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RADC-TR-80-26, Vol I (of two)
Final Technical Report
March 1980

LEVEL II

MODULAR C^3 INTERFACE ANALYSIS (FLEXIBLE INTRACONNECT)
Executive Summary

Hughes Aircraft Company

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RADC-TR-80-26, Vol I (of two) has been reviewed and is approved for publication.

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18. SUPPLEMENTARY NOTES

RADC Project Engineer: James L. Davis (DCLT)
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Time Division Multiple Access	Data Transmission
Data Communications	Data Bus Communications
Local Communications Networks	Tactical Command and Control
Network Protocols	Command, Control and Communications
Fiber Optics	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report documents the results of the concept definition phase for a high capacity wideband general purpose data/communications bussing system. A "Flexible Intraconnect" bus concept is described in terms of its use to achieve physical and functional modularity in the design, implementation and operational deployment of command and control (C^2) centers of the Tactical Air Force (TAF). Flexible Intraconnect (FI) design parameters are established in terms of traffic loading estimates and (Cont'd)

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requirements of evolving configurations of C^2 centers of the TAF. Surveys of data distribution system system architectures, current and developing technologies and C^2 device interfaces are provided. A design of a Flexible Intraconnect having high data rate and capacity, positive flow control and configuration flexibility is documented. A standardized interface for physical and functional device to bus access is described. Descriptions of the major functional elements of the FI are provided along with top level block diagrams. The design was analyzed and preliminary estimates of error performance, reliability, capacity and response times were derived. Results obtained from this phase will be used in specifications for the subsequent development phase of the FI program.

EVALUATION

Command and control capabilities for the Tactical Air Force take too long to develop, do not satisfy the intent of original requirements, cost too much, can't adapt to simple changes and fail to interoperate with other systems. This is caused, in part, by the military acquisition environment itself where systems are developed in isolation by independent program offices, funded in inefficient stages, built as unique packages with rigid capabilities against a set of explicitly stated (but highly volatile) mission sensitive specifications. The resulting designs become over-optimized, needlessly complicated and have little potential for normal growth or addition of new capabilities.

This contract effort represents an important step toward simplifying, organizing and standardizing the connectivity structure of the communications and data processing devices that constitute command and control systems centers. A Flexible Intraconnect bus architecture will permit rapid evolution of C^2 capabilities, orderly adaptation of new functions or revised operating procedures and timely introduction of desirable technological improvements. The FI is intended for immediate application to reduce complexities of existing C^2 centers and will simplify the architecture of systems for future centers, while absorbing greater volumes of information associated with the increasing levels of automation.

The results of this contract are being incorporated in specifications for a program to develop equipment and software, verify technical performance and demonstrate operational advantages and suitability of the Flexible Intraconnect approach. This work was conducted under the Distributed C^2 (R3C) thrust of the Communications and Information Processing for C^2 (RA3) section of the RADC Technology Planning Objectives (TPO) structure.

James L. Davis

JAMES L. DAVIS
Project Engineer

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PART 1
PROJECT REQUIREMENTS AND APPROACH

1. The Technical Problem Was to Design a Flexible Intraconnect That Supports Modular C^3 Goals

92784-1R

- Provide the Transmission Capacity Necessary to Support Present Data Rates and Those Expected in the 1990 Time Frame
- Transfer Data via a Method Which is Transparent to the Contents of the Data Being Exchanged by Intraconnect Users
- Provide a Standard Interface so that Present and Future Devices, Both Simple and Complex, can be Tied into the Net
- Provide for "Sub-Networks" for the Exclusive use of Groups of Designated Devices
- Provide for On-Line (but not Necessarily Dynamic) Reconfiguration of User Devices
- Provide Self-Checking Capabilities and Support the Security Needs of Users
- Transmit Data Over a Five-Mile Range
- Interface with Existing Communications Subsystems such as TCCF, Microwave, Troposcatter, and Satellite

A new method for connecting devices, subsystems, and centers is required in order to achieve a truly modular approach to the operational needs of the Tactical Air Force. Current Tactical Air Force Command, Control, Communications (C^3) Centers, while they provide the required performance, are limited in terms of desired flexibility, adaptability, deployability, interoperability and growth. This is due to the technology available at the time of their design.

A solution to these limitations is the development of modular elements in each of three system segments: hardware, software, and interconnecting links. The goals of such a modular concept would include:

- The ability to configure a wide variety of functionally different centers in a wide variety of sizes
- The capability of introducing new devices in the field as they are developed without center redesign or modification
- The capability for the center commander to reconfigure or reallocate tasks and functions in the field in order to meet a changing environment
- The ability to reimplement current centers as new technology becomes available.

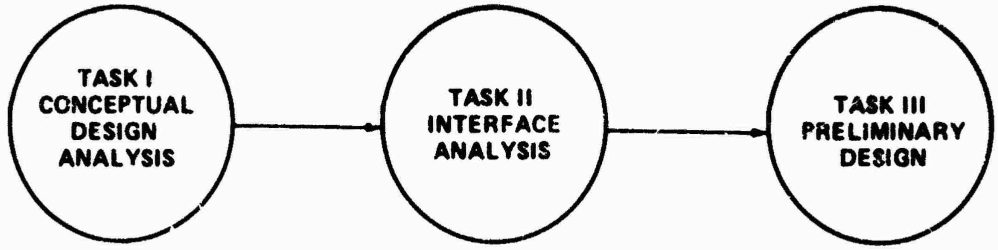
Recent technology advancements have made the development of a cost effective modular design, achieving the goals listed above, feasible and timely. Key areas of the new technology are microprocessors, LSI, and fiber optics.

The Modular C^3 Flexible Intraconnect analysis study is aimed at providing a concept for the connecting links that support the modular C^3 design concept.

In order for the modular C^3 concept to be successful, the intraconnect design must strive to reach the same goals as other (modular C^3) elements. Specific FI requirements to meet these goals are listed above.

2. An FI Concept, an Interface Standard, and a Preliminary Design Were Developed in a Three-Task Program

92784-2R



- Analyze Present and Future Tactical C^3 Centers
- Develop Connectivity and Capacity Requirements
- Develop Candidate FI Concepts
- Select Most Effective FI Design Concept

- Develop Standard Interface
- Analyze and Refine FI Local and External Interfaces
- Analyze Interface Adapter Requirements
- Concept Verification Analysis

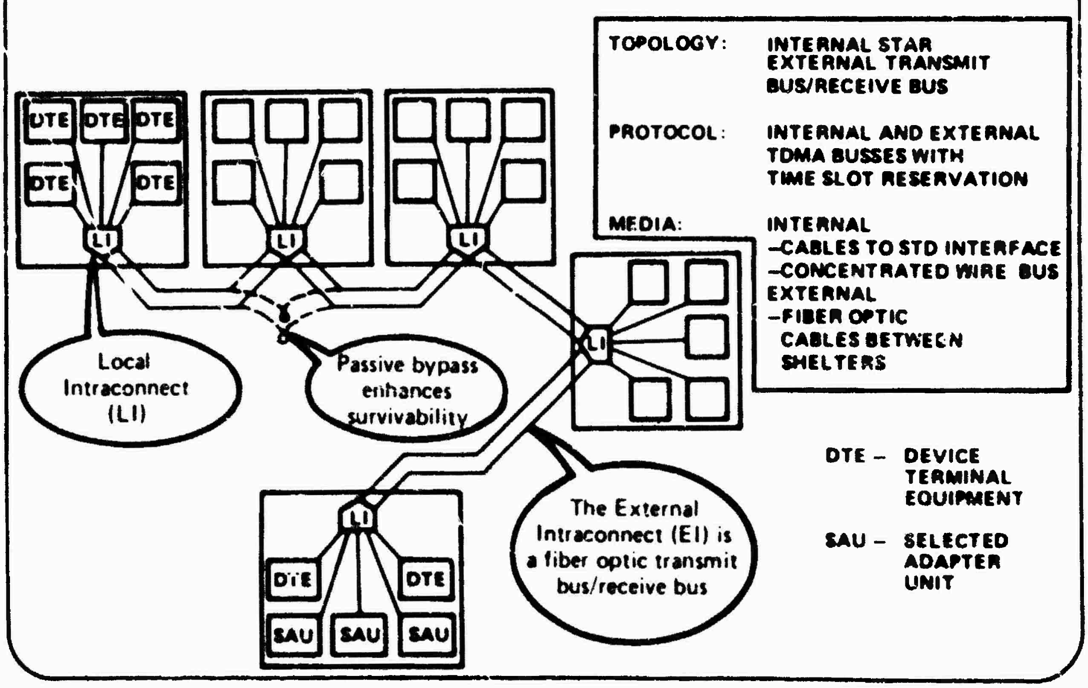
- Develop and Analyze FI Functional Design
- Develop Preliminary Implementation Approach
- Identify FI Characterisitcs
- Develop FI Management Approach
- Reliability and Error Analyses

In an intensive study, analysis, and design effort over a period of 17 months, Hughes and the Government in a joint effort, developed a Flexible Intraconnect (FI) concept and preliminary design for interconnecting the devices, facilities, and shelters of Tactical Command and Control Centers. The FI is designed with the flexibility to meet current, planned, and future requirements as they are projected to the post 1990 time frame. This design was accomplished by an interdisciplinary team of technical and operational specialists, interactively developing the FI design in a three-task effort: 1) developing an FI design concept, 2) analyzing FI interfaces, and 3) developing a preliminary FI design. A major part of the effort involved analyzing the configurations and operations of existing and planned TAF C^3 Centers, studying the TAFIIS Master Plan, developing current and potential requirements for the FI, and verifying the design results.

A comprehensive survey of data distribution system architectures and device technologies, and thorough analysis of device interfaces was performed. This resulted in an FI design which exploits current and developing technologies to provide a high data rate and connectivity capacity, positive flow control, and configuration flexibility in a Star/Bus hierarchial topology. In addition, a standard interface for connecting C^3 devices to the FI was developed.

PART 2
TECHNICAL RESULTS

1. A Star/Bus Architecture Optimizes the FI Design for Clustered C^3 Devices in Widely Dispersed Shelters



The FI can be described in terms of its architectural components: Topology, protocol, and media. The FI design applies to a single facility as well as multi-facility centers. The figure illustrates the FI architecture applied to a five shelter C^3 center. The shelters may be colocated or dispersed over a wide area (up to 5 miles). The star/bus topology provides for star connection of clustered equipments to the Local Intraconnect (LI), a concentrated 90 Mb/s TDMA bus. The LIs, located within shelters of a multi-operations-module center (or near clustered equipments within a single facility center) are inteconnected by the External Intraconnect (EI) which is a distributed TDMA bus using fiber optic cables. As a result, all devices in all shelters on the FI are virtually interconnected. Double lines are shown in the figure to symbolize a transmit bus and a receive bus designed to provide efficient propagation time compensation. Point-to-point fiber optic connections with three 20 Mb/s fibers per bus result in 60 Mb/s EI capacity. To increase survivability of the system, a passive fiber-optic cable bypass capability is provided at each shelter to allow FI operation to continue in the event of shelter losses.

The protocol of data transfer on the LIs and the EI is a time slotted reservation system on a TDMA bus. Although the protocols are generally the same, there are differences based on their physical structures and control mechanisms. For example, even though the Local Intraconnect and External Intraconnect operate within themselves as synchronous TDMA busses, they are not synchronized with each other. While the External Intraconnect operates with control distributed between shelters, each Local Intraconnect operates under a central control.

2. The FI is Designed for High Capacity With a Low Risk Implementation

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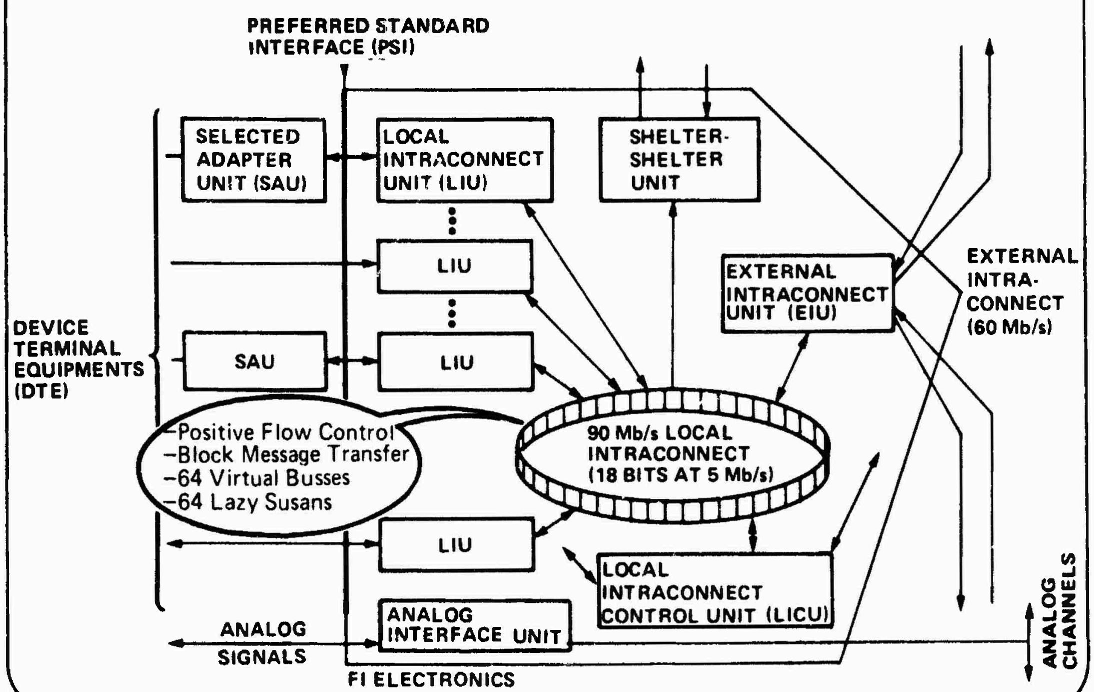


The Local Intraconnect is a concentrated (inches long) set of 18 parallel TDMA busses operating at a nominal 5 Mb/s which results in a total capacity of 90 Mb/s. Local Intraconnect Units provide buffer and control interfaces to the Device Terminal Equipments (DTE) through a standard interface. In a shelter application, the standard interface will be available at receptacles distributed on the internal shelter walls for convenient connection of devices to the FI. Selected Adapter Units (SAU) convert non-standard interfaces to the Preferred Standard Interface (PSI). The external intraconnect unit (EIU) provides the asynchronous buffering and gating between the local and external intraconnects. A Local Intraconnect Control Unit (LICU) provides timing, configuration, and reservation control for the LI. Special signals, such as analog signals, may be provided for by digitizing them in an SAU and handling them in the FI as data messages, or they may be handled in separate channels. A Shelter-Shelter Unit provides for direct connection between shelters or facilities not otherwise connected by the External Intraconnect.

FI modularity provides for C^3 center configuration flexibility in field operations for center build-up, scale-down, and role changing, so necessary to support rolling force and leap-frog tactics in future mobile environments. Configuration flexibility and wide dispersement of shelters (up to 5 miles) promotes survivability of C^3 centers.

3. Three FI Data Transfer Systems Satisfy Current and Future Requirements

92784-5R

Block Message
- Variable Length Messages up to 18 Kilobits
- Discrete Addressed Messages
- Broadcast Messages

Virtual Bus
- Guaranteed/Protected Capacity Within the FI
- Limited Broadcast
- Metering Rate Control
- User Managed
- 63 Virtual Busses, Maximum

Lazy Susan
- "Virtual Ring"
- Time Ordered Sequential Processing
- User Managed
- 63 Lazy Susan Nets, Maximum

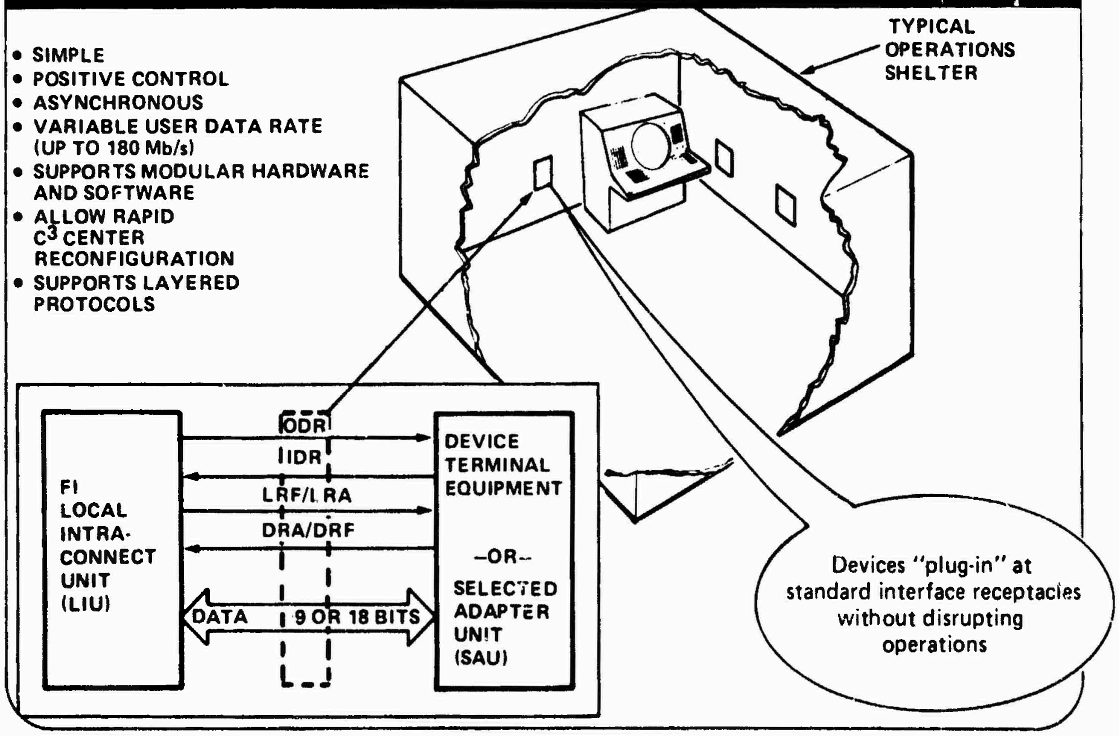
All information is transferred within the FI as digital data in message packets. Three ways of handling these messages provide the flexibility needed to distribute information between a wide variety of users. The three message transfer systems are: the Block message system, the Virtual Bus system, and the Lazy Susan system.

The Block message transfer system provides a control mechanism for transferring blocks of data from source devices to specific receiving devices via discrete addressed messages, and to all devices on the FI via broadcast messages. Typical uses of the system include the large data transfers associated with total data base relocations, interactive exchanges such as command-response messages and digital voice traffic.

The Virtual Bus (VB) System reserves portions of the FI capacity for designated families of users. Each of these portions (Virtual Busses) guarantee a predetermined but variable transfer capacity. A sequence number scheme provides for "metering" and ordering user message transmissions within each of the VBs so that device transmissions can be regulated according to specific data rate requirements. All user devices within a VB family receive all transmissions on the VB. The VB system supports distributed processing, the "data base on the bus" concept and computer resource sharing.

The Lazy Susan (LS) System is operated within the FI in a manner very similar to the VB system. Each user on a LS net appears to be operating in a ring network, where messages circulate to all members in a time ordered manner, as plates on a "lazy susan". The LS nets are used where sequential time ordered distributed processing is important, and where processes rather than addresses are critical.

4. A Simple, Positively Controlled Standard Interface Allows Equipment to "Plug-In" to C³ Centers



A preliminary interface standard (termed the Preferred Standard Interface, PSI) was developed with the intent that it would become a Military STANDARD, guiding the design of future Modular C^3 equipments. For example, as new or more capable display devices, computers and communications equipment are developed using the standard, modular C^3 centers can be upgraded with those devices without redesign of the centers. In the interim, existing non-standard devices are accommodated in modular C^3 centers via Selected Adapter Units, which convert other interfaces to the PSI.

The PSI consists of 4 unidirectional control lines and 18 bidirectional data lines operating in an asynchronous half duplex mode. The control line complement is minimal due to the protocol of message transfer and to the FI related control information in the message headers. Messages are transferred in either full word segments over 18 data lines or in halfword segments over 9 data lines. The protocol of message transfer accepts a wide range of transfer rates from 180 megabits per second maximum, to one word per 10 seconds, minimum.

The standard for the message format specifies a header section and a data section. The header section consists of 16 18-bit words. The information fields in the header have been defined so that each header word has only one interpretation. The data section consists of up to 1019 18-bit data words and 5 18-bit error check words.

The PSI message protocol provides for software modularity and interoperability via a "layered" approach consistent with developing national protocol standards.

5. FI Operation Provides Positive Control of FI Message Transfers

9784-7P

- Reservation Access Protocol for Network Stability
- Pretransmission Path Clearance to Eliminate Bottlenecks
- Acknowledge Scheme to Confirm Successful Message Transfers
- Management Scheme to Simplify Operator Tasks

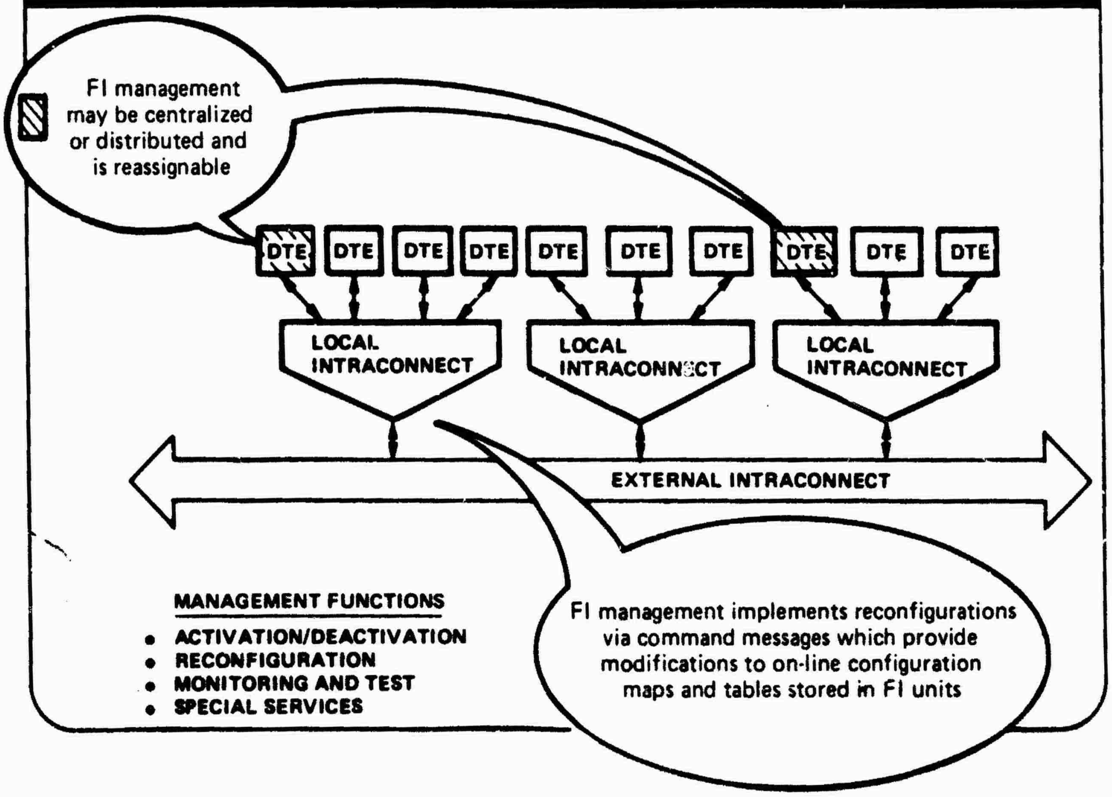
The criteria of highest importance in the design of the FI was "positive control" of system operation. The selection of a reservation method of access to the bus, (with a few assigned slots to support control functions) is directly related to this criteria. The discipline inherent in the reservation protocol was deemed more desirable than the implementation efficiency of a contention protocol because of the latter's potential for "lock-up" and "run away" under heavy load conditions.

The same criteria led to the "front-end" handshake and the ACK/NACK techniques. The handshake technique establishes a clear path between source and destination immediately prior to transmission of a message, so that messages do not load up the bus during futile attempts to transmit data to a destination which is "not ready." The ACK/NACK is an immediate response from the destination signifying either that the message was successfully received or that some reception problem existed.

"Positive Control" of system operations also dictated that the design require minimum interaction between the FI and its operators for simple operator actions. This was carried out by providing an effective FI Management scheme that permits automatic start-up and operation in a basic configuration with no operator interaction. Provision is made for FI reconfiguration under software control.

6. FI Flexibility and Stability is Achieved by Partitioning Management From Control

92784-8R



On-line FI control functions are implemented in FI elements, providing the ability within the FI to activate itself and operate with a basic capability and configuration, and without an off-line FI management function. However, the FI is also designed so that an FI management function, implemented in the hardware and/or software of Data Terminal Equipment, can reconfigure the FI (and hence the center). FI monitoring, test functions, and other special services can also be performed by FI management. These management functions can be centralized or distributed among DTE elements, giving C^3 Centers the flexibility necessary for rolling force or leap frog tactics and for increasing system survivability.

The separation of FI control implementation from FI management implementation is important in another aspect. FI operation does not depend on continuation of FI management services. That is, not only can the FI operate with its built in basic configuration after start-up, but should FI management services exist and subsequently be lost, FI operation will continue with its most recent configuration in effect.

The FI can be initiated and operated in the field by personnel with a minimum of training. Major reconfigurations can be achieved via prerecorded devices or by cook book style manual inputs. Constant system visibility is provided automatically by designed-in status reporting. In addition, more detailed status and test information is provided on demand by the FI management function. The FI management function enhances C^3 operation by using its off-line processing functions to assist unsophisticated user devices with header construction, and to assist Virtual Bus and Lazy Susan management.

7. The Flexible Intraconnect is a Key Element of the Modular C^3 Concept

92784-9R

- The FI Concept Meets TAF MOD C^3 Goals
- A MOD C^3 Standard Interface Promotes C^3 Interoperability
- The Design Exploits Modern Technology and is Ready for Detailed Design and Implementation

The Mod C^3 concept is no longer just an idea. A key element, the FI, has been conceived, standard interfaces have been defined, preliminary design has been completed and the results have been verified. The Mod C^3 concept, with a Flexible Intraconnect providing programmable connectivity, along with standard and adaptable interfaces, will reduce the cost of acquiring and operating new systems. Interoperability between equipments and centers will improve.

The FI design meets the requirements of current and planned TAF C^3 centers through the 1990s. It also fulfills the modularity, flexibility, interoperability, and survivability goals of the Mod C^3 concept. The concept and requirements were developed and analyzed based on detailed analyses of C^3 center configurations and operations. The most effective approach was selected from a set of six candidates and was verified against requirements of existing and planned C^3 centers.

The FI design incorporates high capacity, configuration flexibility, positive control, and stable operation. It can be implemented today, but exploits advanced technology. (The external Intraconnect is designed for fiber optic implementation. Control functions take advantage of microprocessor capabilities and surface acoustic wave device potential.) Future growth and development is provided for in the functional and physical modularity of the design. FI connectivity and configuration are controlled by software, providing stable operation. The FI electronics package, (all the FI hardware required in each shelter) can be packaged in less than one-third of an equipment rack.

PART 3
ADDITIONAL DEVELOPMENT

1. Recommendations for Continued Development of the Flexible Intraconnect

92784-10R

1. Design and fabricate FI Units.
2. Develop a realistic operational configuration in which to test the intraconnect (A test bed).
3. Develop a scenario and appropriate simulation programs/equipment to exercise the intraconnect.
4. After verification of the design in the test bed, install the FI in a TAF C^3 center for further evaluation.

A practical, "ready to implement" FI design concept which meets Tactical Air Force Modular C^3 goals has been developed under this contract. It is recommended that the preliminary FI design be carried forward in a developmental program to build the Flexible Intraconnect for demonstration and evaluation, and to support other Mod C^3 studies. It is recommended that the evaluation be performed using typical C^3 equipment in a real or simulated operational environment. This can be accomplished in a program during which the above listed tasks are performed.

The Contractor believes the above outlined program will establish the merit of the Flexible Intraconnect concept and ultimately lead to a truly modular implementation of Tactical Air Force Command and Control Centers.

GLOSSARY

ACK/NACK	- Acknowledge/Negative Acknowledge
C^3	- Command, Control and Communications
DTE	- Device Terminal Equipment
EI	- External Intraconnect
EIU	- External Intraconnect Unit
FI	- Flexible Intraconnect
LI	- Local Intraconnect
LICU	- Local Intraconnect Control Unit
LIU	- Local Interface Unit
LS	- Lazy Susan
LSI	- Large Scale Integrated
Mb/s	- Megabits per second
PSI	- Preferred Standard Interface
SAU	- Selected Adapter Unit
TAF	- Tactical Air Force
TAFIIS	- Tactical Air Force Integrated Information System
TCCF	- Tactical Communications Control Facility
TDMA	- Time Division Multiple Access
VB	- Virtual Bus

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